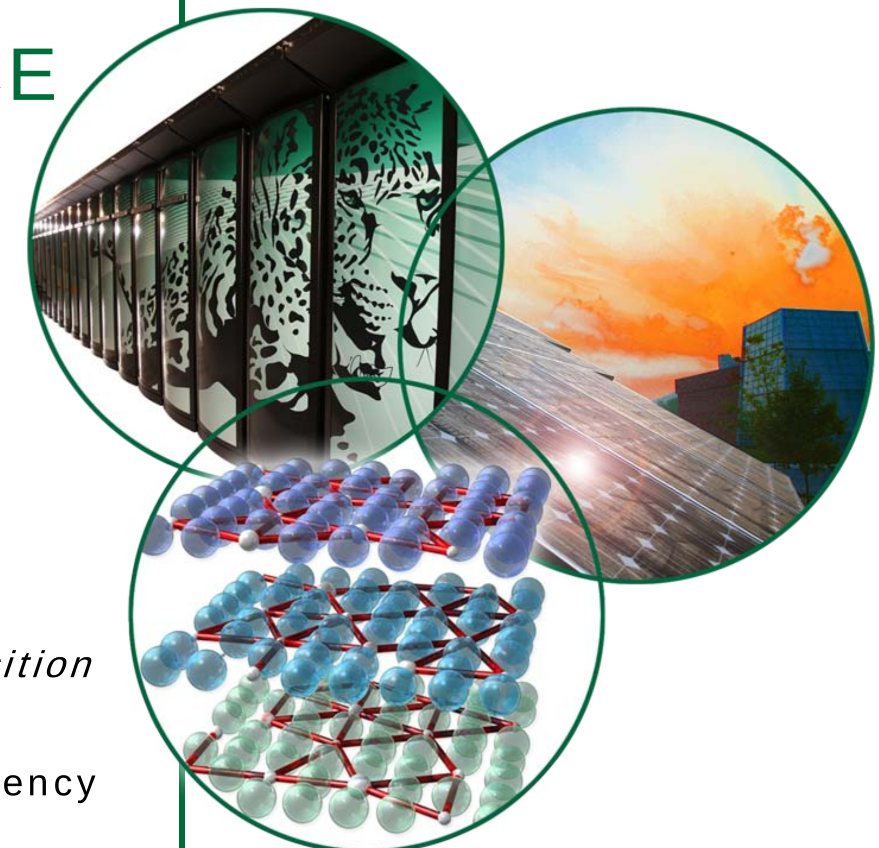
REVIEW OF TECHNICAL STUDIES IN THE UNITED STATES IN SUPPORT OF BURNUP CREDIT REGULATORY GUIDANCE FOR TRANSPORT



John Wagner, Cecil Parks,
Don Mueller, Ian Gauld
Oak Ridge National Laboratory

International Workshop on Advances in Applications of Burnup Credit for Spent Fuel Storage, Transport, Reprocessing, and Disposition

Organized by: Nuclear Safety Council of Spain (CSN) and the International Atomic Energy Agency (IAEA)

October 27 – 30, 2009, Cordoba, Spain

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Introduction

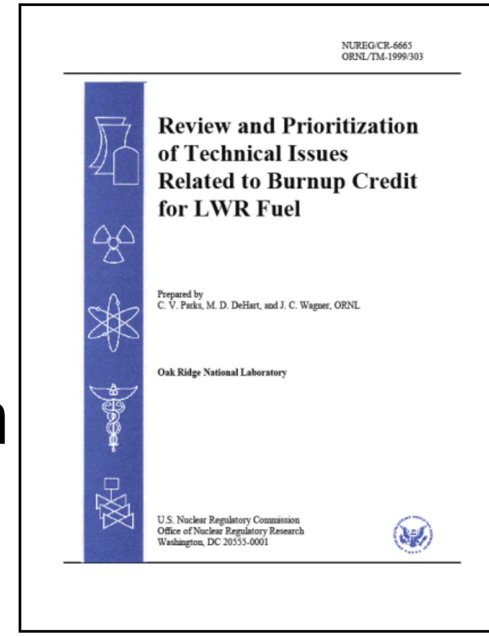
- Interest in burnup credit has motivated numerous technical studies, domestically and internationally
- The number of countries interested in burnup credit increases each year
- The purpose of this presentation/paper is to draw attention to existing publications that may be useful to people entering the field of burnup credit

Introduction

- In 1999, the US NRC initiated a research program with ORNL to develop guidance and technical bases for allowing and expanding the use of burnup credit in PWR SNF storage and transport applications
- The research program attempted to systematically address technical issues in the pursuit of expanding regulatory guidance for the use of burnup credit
- The program produced a number of reports that are publically available

Baseline Report, 1999

- Reviewed application areas
- Reviewed previous technical studies
- Reviewed/identified parameters/phenomenon
- Reviewed technical and licensing issues
- Proposed research and prioritization
- Status of burnup credit programs in other countries



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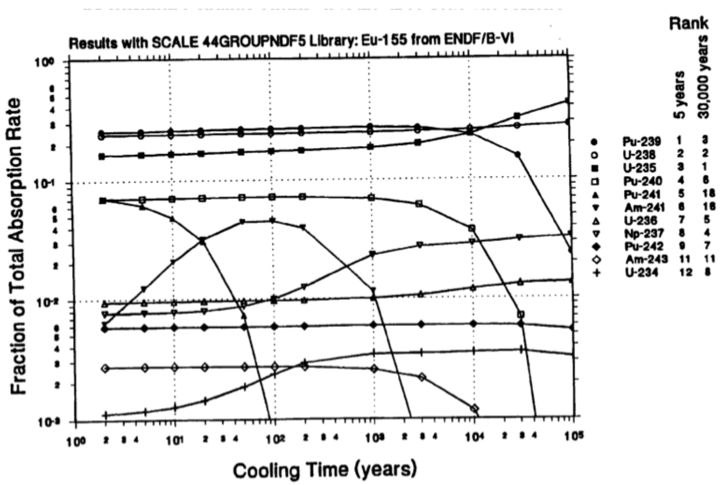
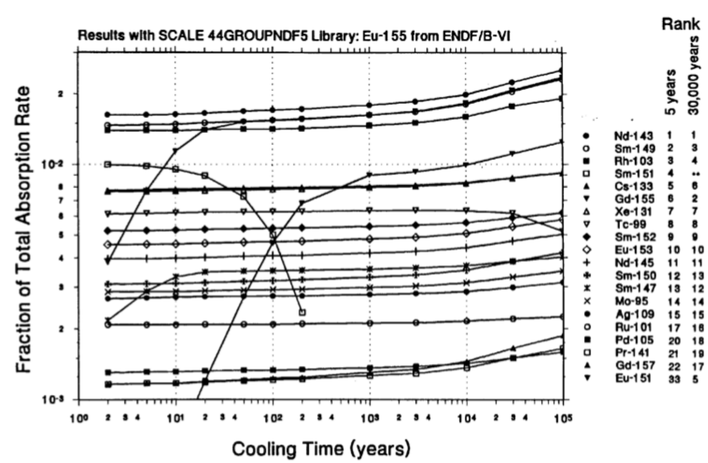
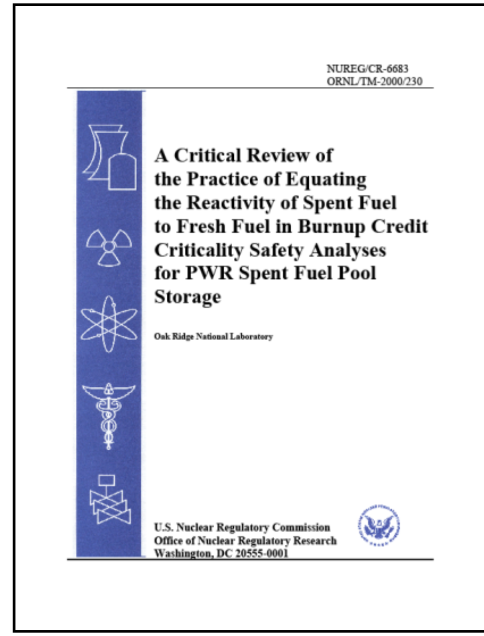




Reactivity Equivalencing, 2000


NUREG/CR-6683
ORNL/TM-2000/230

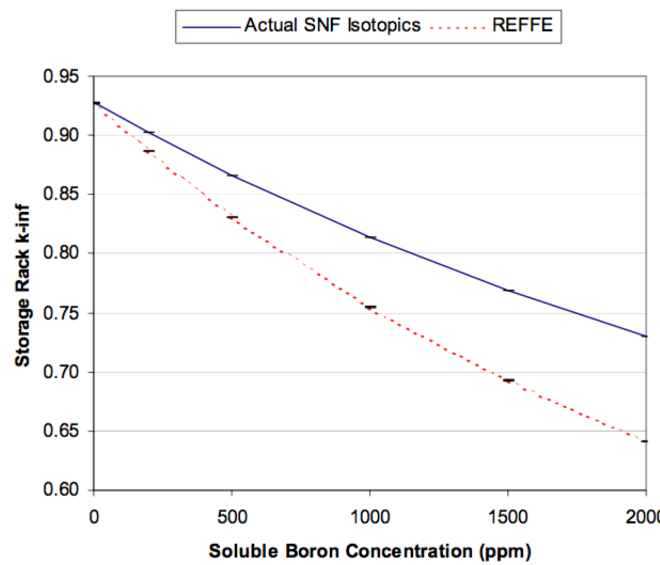
A Critical Review of the Practice of Equating the Reactivity of Spent Fuel to Fresh Fuel in Burnup Credit Criticality Safety Analyses for PWR Spent Fuel Pool Storage

Oak Ridge National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

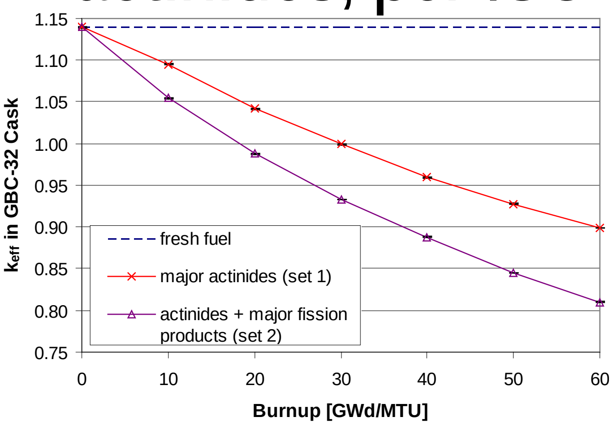
NUREG/CR-6683

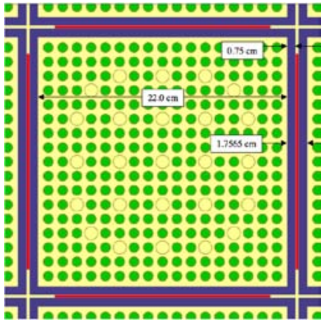
- Investigated the practice of equating the reactivity of spent fuel to the reactivity of fresh fuel, referred to as *reactivity equivalencing for PWR SFP conditions*
- Looked at normal and accident conditions, as well as various storage configurations
- Demonstrated practice to be acceptable, when used properly
- Demonstrated inaccurate and non-conservative reactivity estimates when used improperly



Computational Benchmark, 2001

- Defined representative high-capacity cask
- Estimated additional reactivity margin available from fission products and minor actinides, per ISG-8 recommendation






NUREG/CR-6747
ORNL/TM-2000/306

Computational Benchmark for Estimation of Reactivity Margin from Fission Products and Minor Actinides in PWR Burnup Credit

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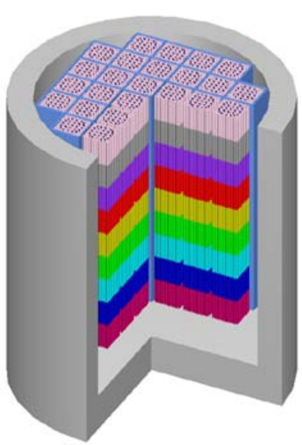
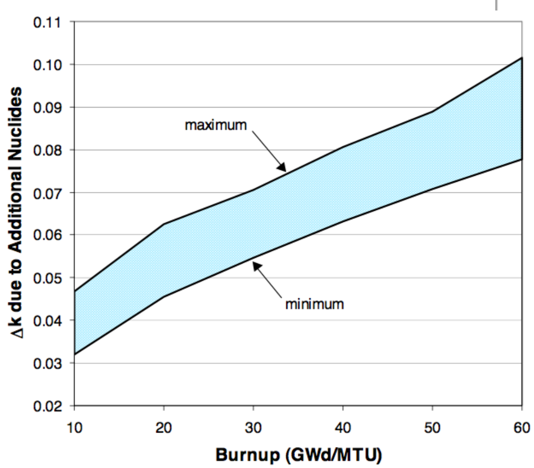
NUREG/CR-6747

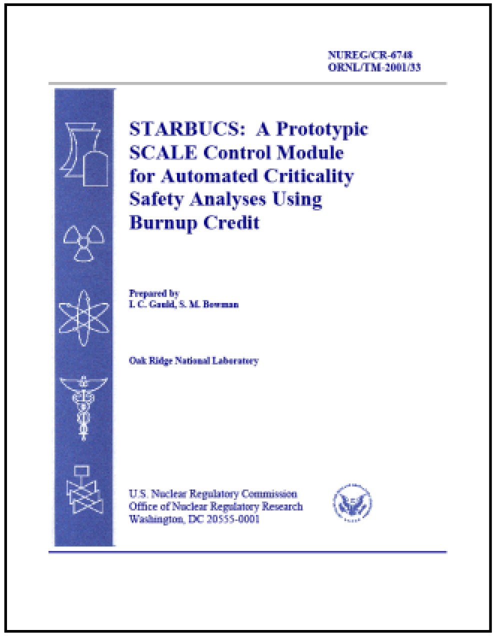
Table 15 Individual components of the reduction in k_{eff} as a function of burnup and cooling time for fuel of 5 wt % ^{235}U initial enrichment

	Δk values due to the various nuclide sets			Contribution to total reduction in k_{eff}	
Burnup (GWd/MTU)	Major actinides (set 1)	Additional nuclides (set 3)	Total (set 2)	Major actinides (set 1)	Additional nuclides (set 3)
0-year cooling time					
10	0.04286	0.03563	0.07849	54.61%	45.39%
20	0.08854	0.05156	0.14010	63.20%	36.80%
30	0.12911	0.06144	0.19055	67.76%	32.24%
40	0.16453	0.06806	0.23259	70.74%	29.26%
50	0.19746	0.07552	0.27298	72.33%	27.67%
60	0.22739	0.08263	0.31002	73.35%	26.65%
5-year cooling time					
10	0.04334	0.04538	0.08872	48.85%	51.15%
20	0.09339	0.06249	0.15588	59.91%	40.09%
30	0.13712	0.07054	0.20766	66.03%	33.97%
40	0.17538	0.07856	0.25394	69.06%	30.94%
50	0.20939	0.08761	0.29700	70.50%	29.50%
60	0.24198	0.09395	0.33593	72.03%	27.97%





SCALE BUC Sequence, 2001


NUREG/CR-6748
ORNL/TM-2001/33

STARBUCS: A Prototypic SCALE Control Module for Automated Criticality Safety Analyses Using Burnup Credit

Prepared by
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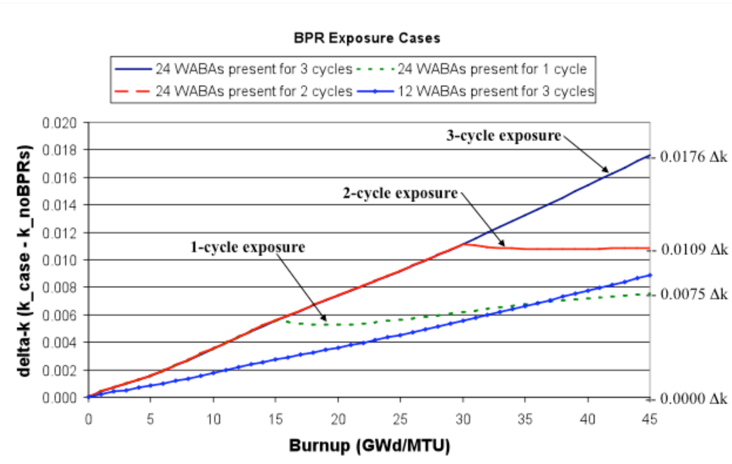
NUREG/CR-6748

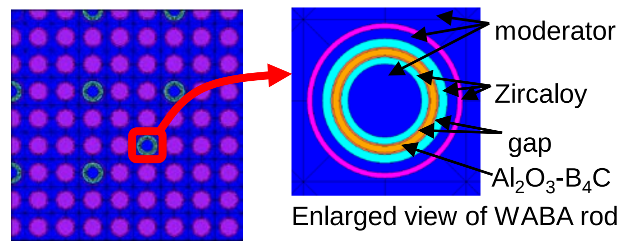
- STARBUCS sequence to automate burnup credit analyses for UO_2 SNF systems
- Performs integrated depletion analysis, cross-section processing, and Monte Carlo calculations for 3-D systems
- Relevant input options to represent
  - Irradiation conditions
  - Cooling time
  - Nuclides relevant to burnup credit
  - Axial and radial variation of burnup
  - Isotopic composition uncertainties
- Used extensively at ORNL to study burnup credit issues

See presentation this afternoon for latest developments:
"Enhancements to the Burnup Credit Criticality Safety Analysis Sequence in SCALE", Radulescu and Gauld

Burnable Poison Rods, 2002

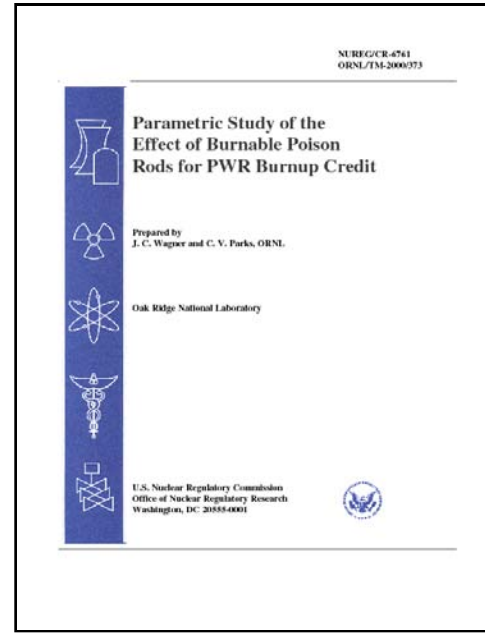
- Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions





Enlarged view of WABA rod

Lower-right quadrant of W17x17 assembly with 24 WABA rods present



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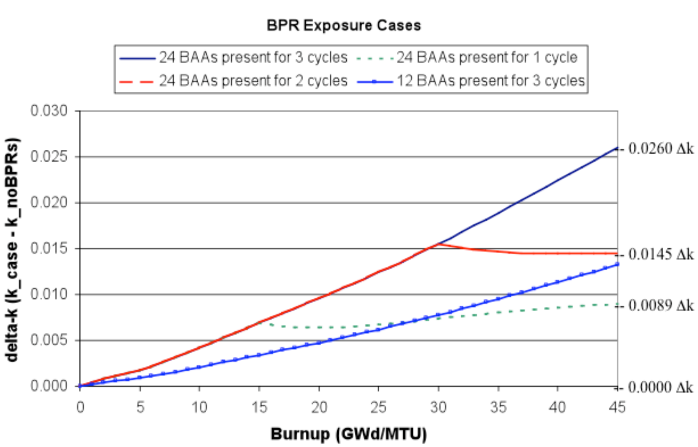
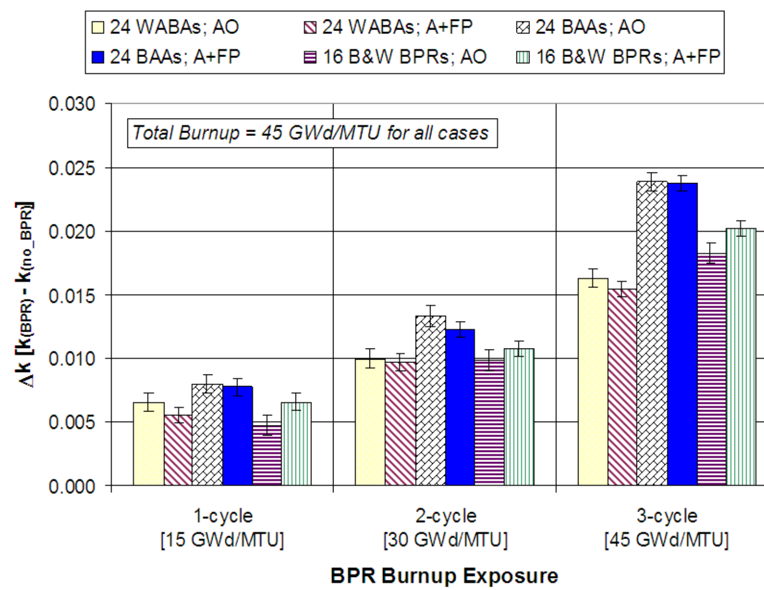
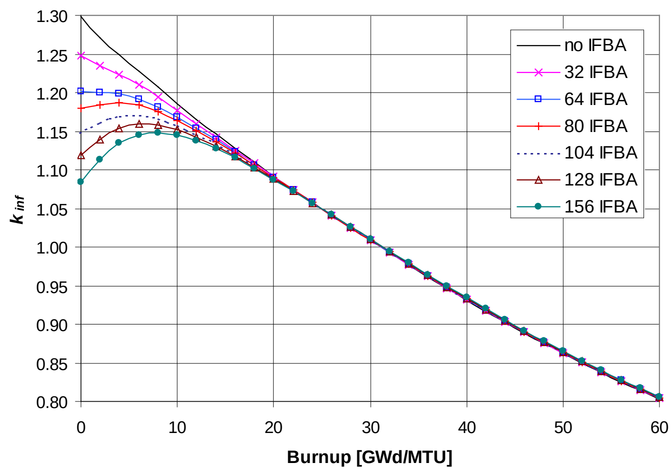
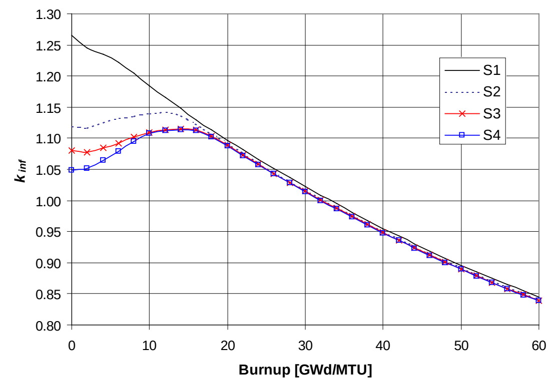


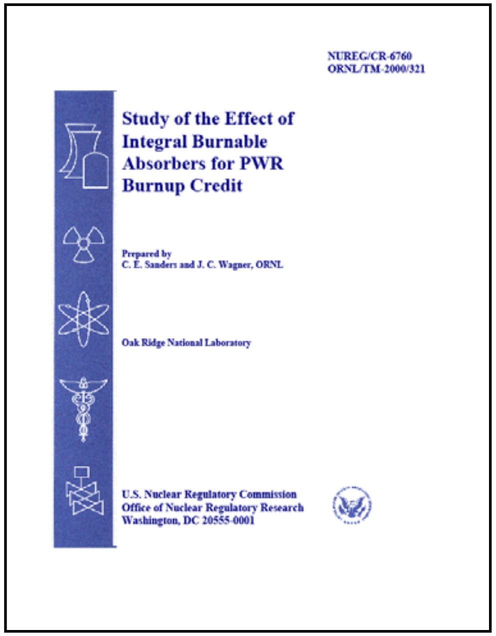


Integral Burnable Absorbers, 2002

- Investigated effect of IBAs on reactivity, ZrB_2, UO_2-Gd_2O_3, UO_2-Er_2O_3, Al_2O_3-B_4C






NUREG/CR-6760
NUREG/CR-6760
ORNL/TM-2000/321

Study of the Effect of Integral Burnable Absorbers for PWR Burnup Credit

Prepared by C. E. Sanders and J. C. Wagner, ORNL

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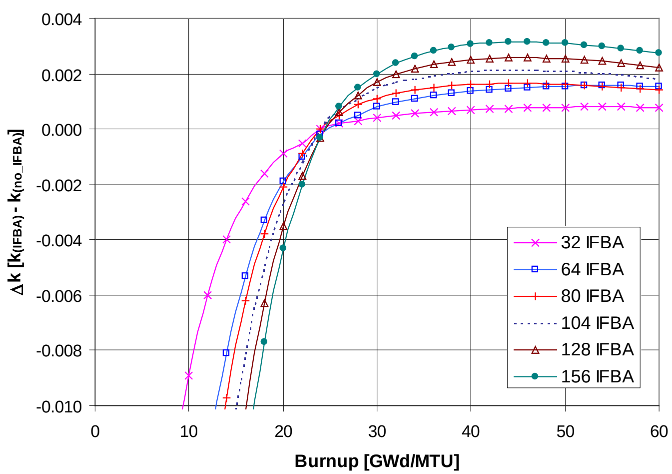
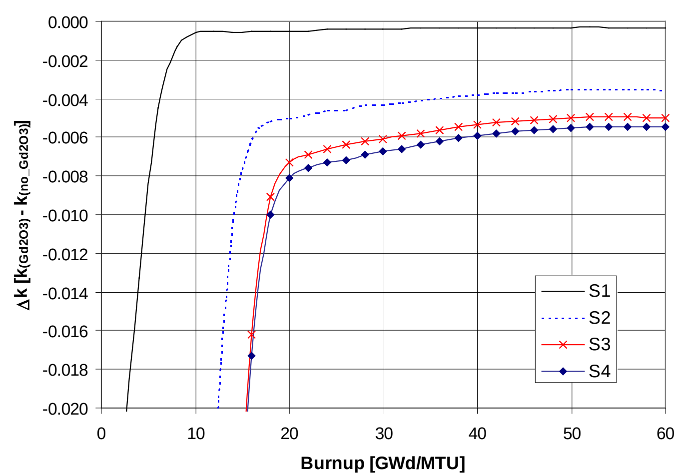
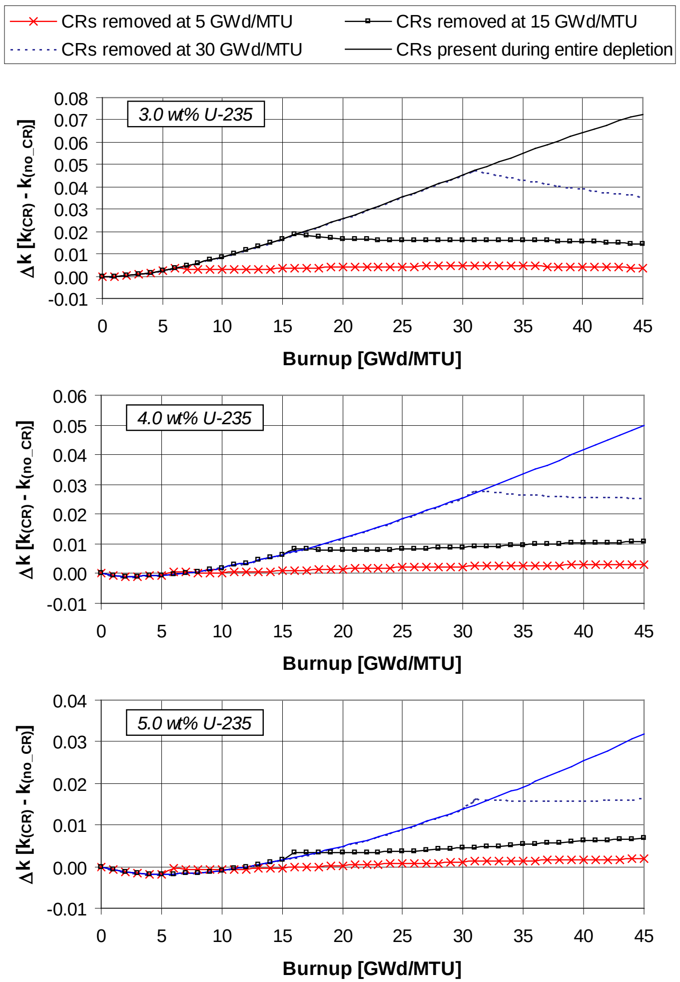


UO_2-Gd_2O_3

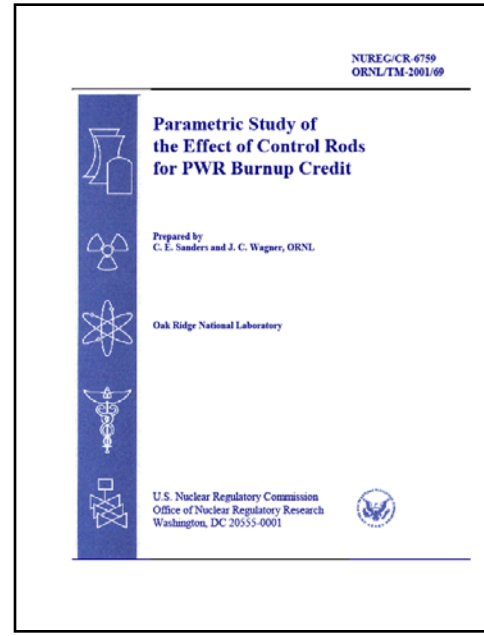


Control Rods, 2002

- Investigated effect of CRs on reactivity for CR/APSR designs & exposure conditions



- W, B&W, and CE designs considered


NUREG/CR-6759
ORNL/TM-2001/69

Parametric Study of the Effect of Control Rods for PWR Burnup Credit

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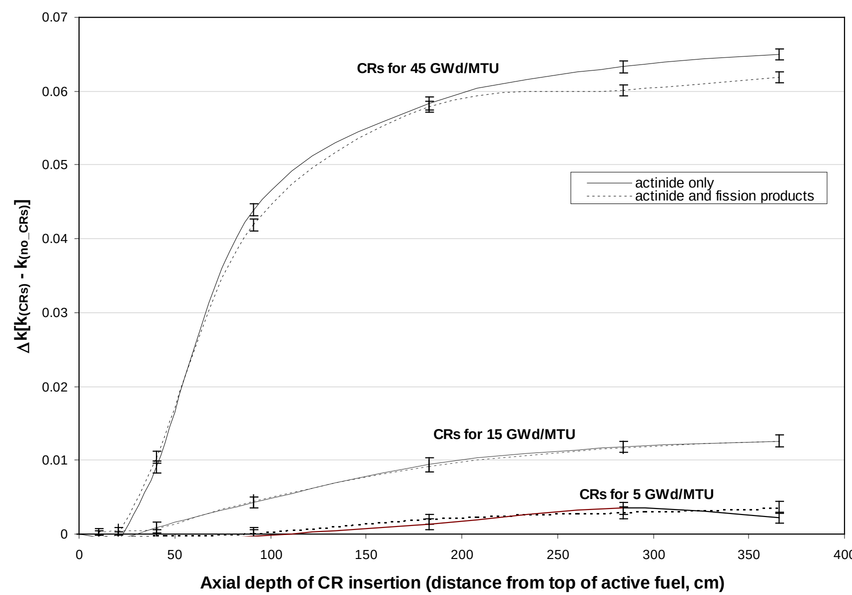
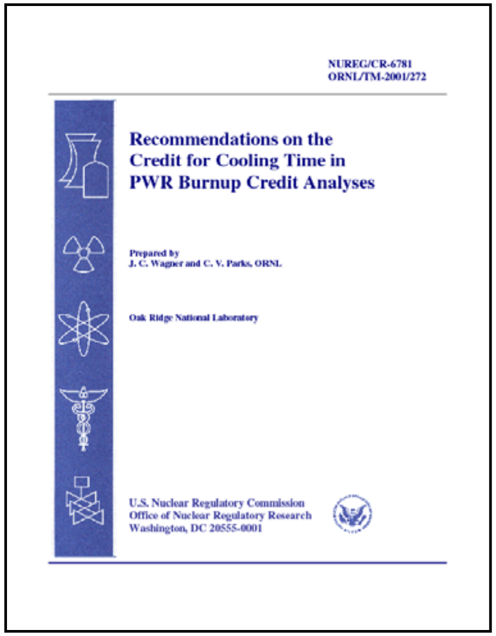
NUREG/CR-6759



Cooling Time, 2003

- Examined reactivity behavior as a function of cooling time to assess the possibility of modifying guidance recommendation


NUREG/CR-6781
ORNL/TM-2001/272

Recommendations on the Credit for Cooling Time in PWR Burnup Credit Analyses

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Office of Nuclear Regulatory Research
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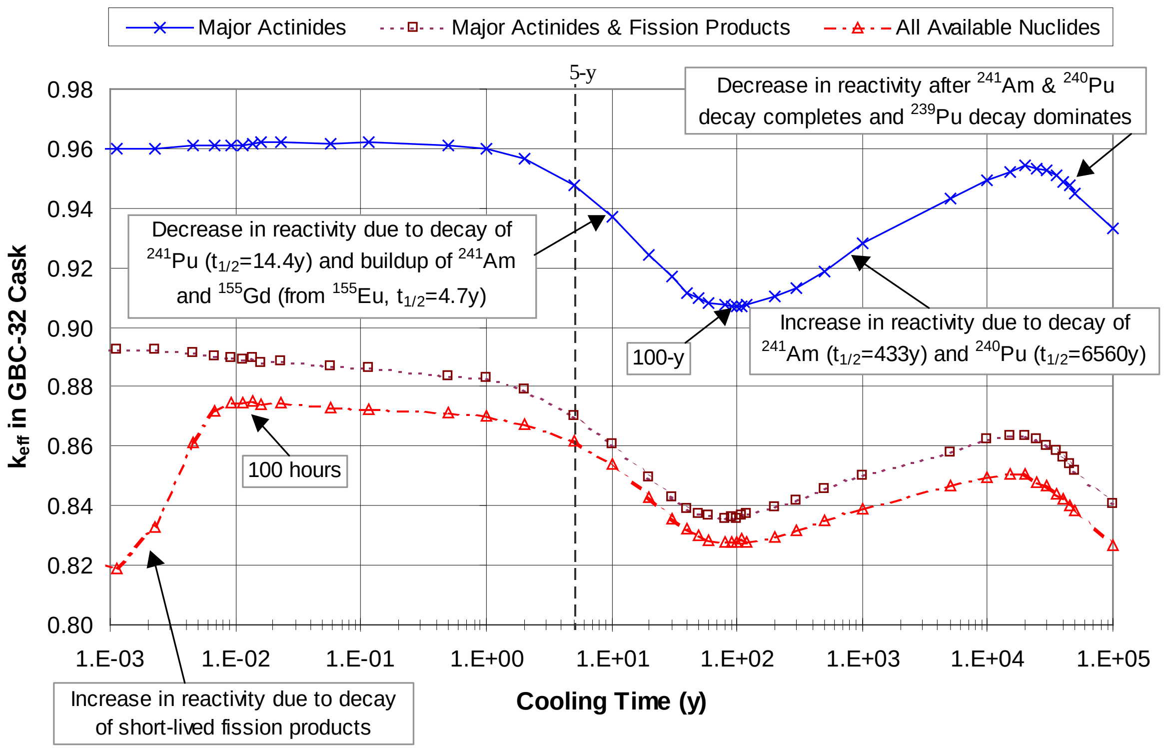
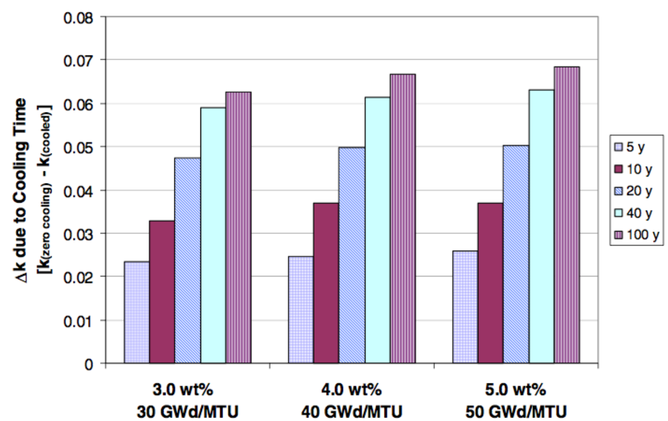
NUREG/CR-6781





Axial Burnup, 2003

- Examined effect of axial burnup on reactivity
- Examined available database of profiles to
  - identify profiles that maximize, *keff,*
  - *assess its* adequacy for use in safety analyses
  - investigate the existence of trends with fuel type and/or reactor operations


NUREG/CR-6801
ORNL/TM-2001/273

Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses

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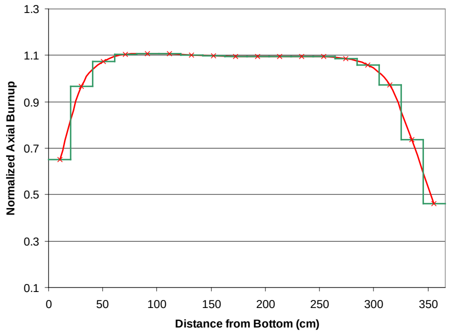
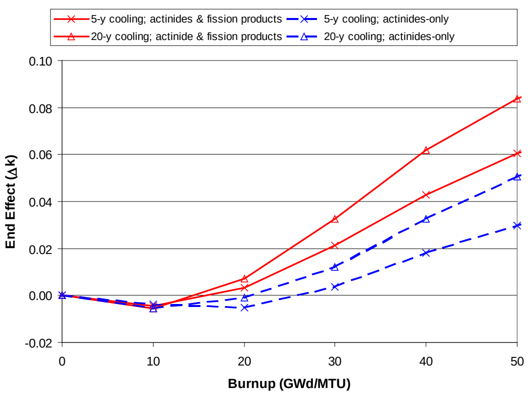
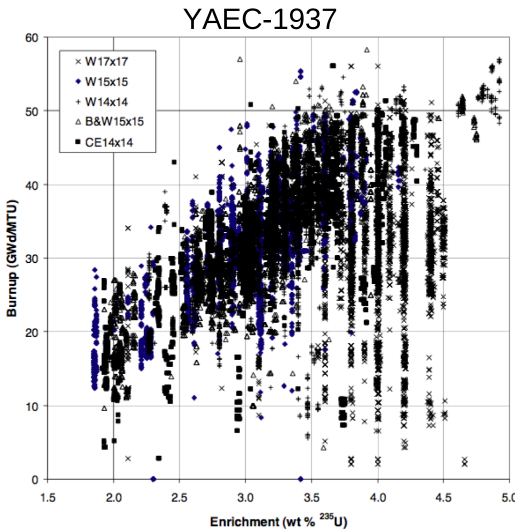
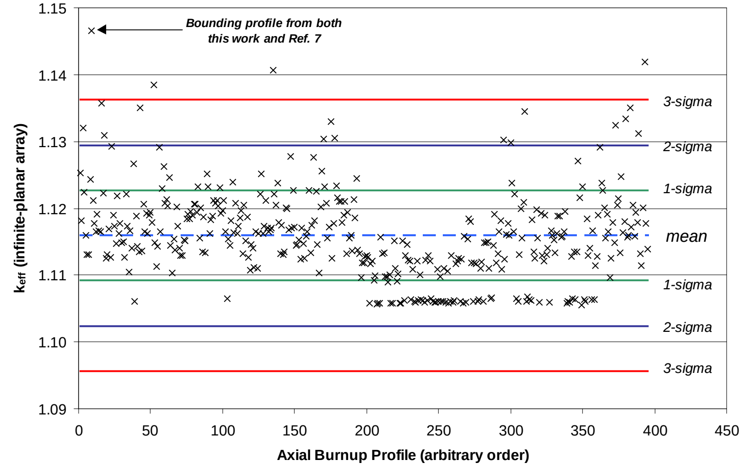
NUREG/CR-6801



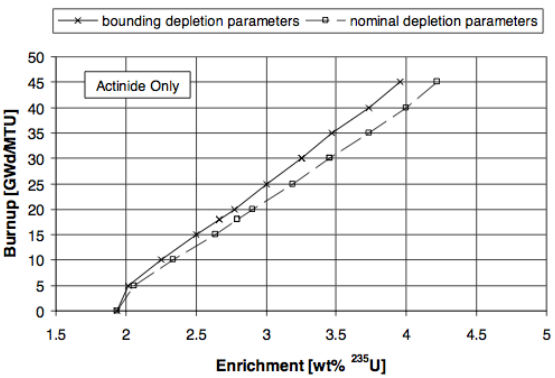


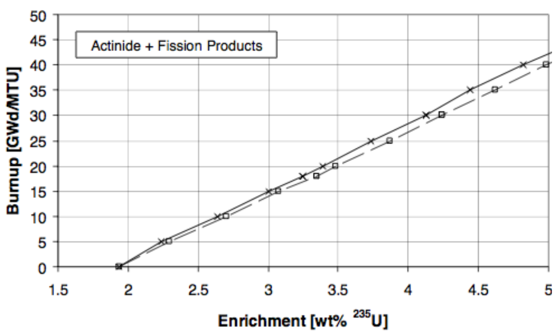


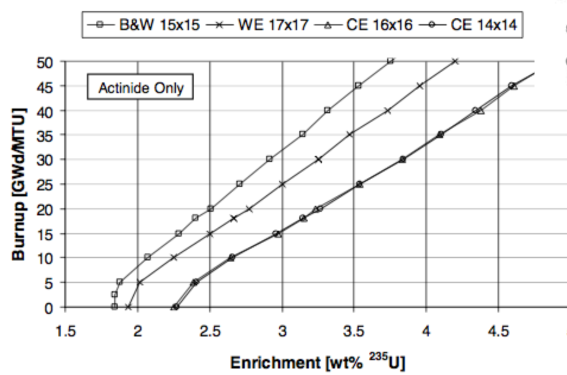


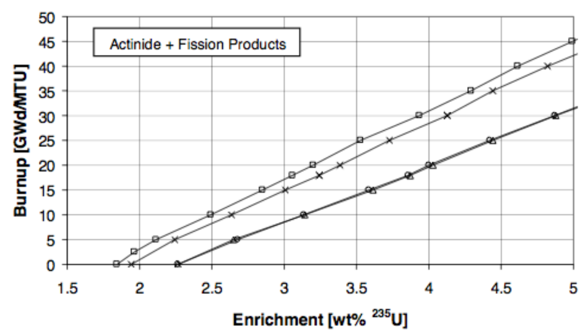
Reactivity Margins, 2003

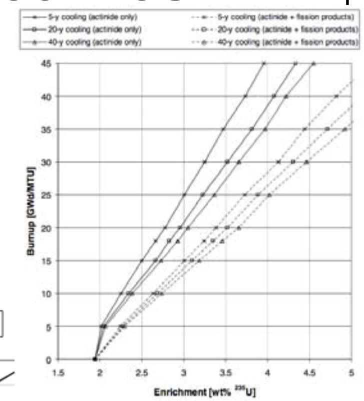
- Examined impact of depletion & criticality analysis assumptions on loading curves

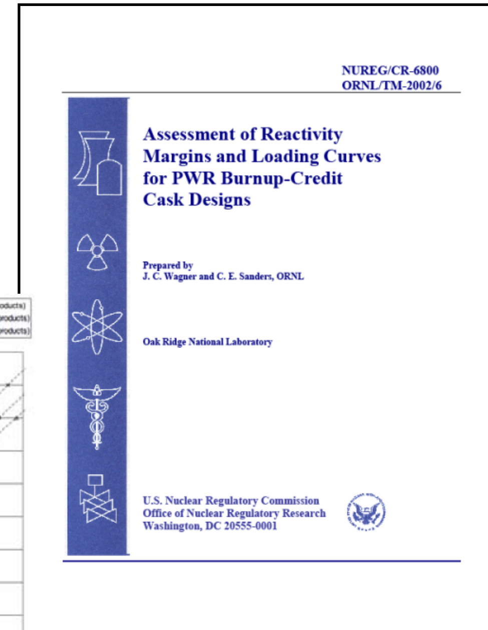











NUREG/CR-6800
ORNL/TM-2002/6

Assessment of Reactivity Margins and Loading Curves for PWR Burnup-Credit Cask Designs

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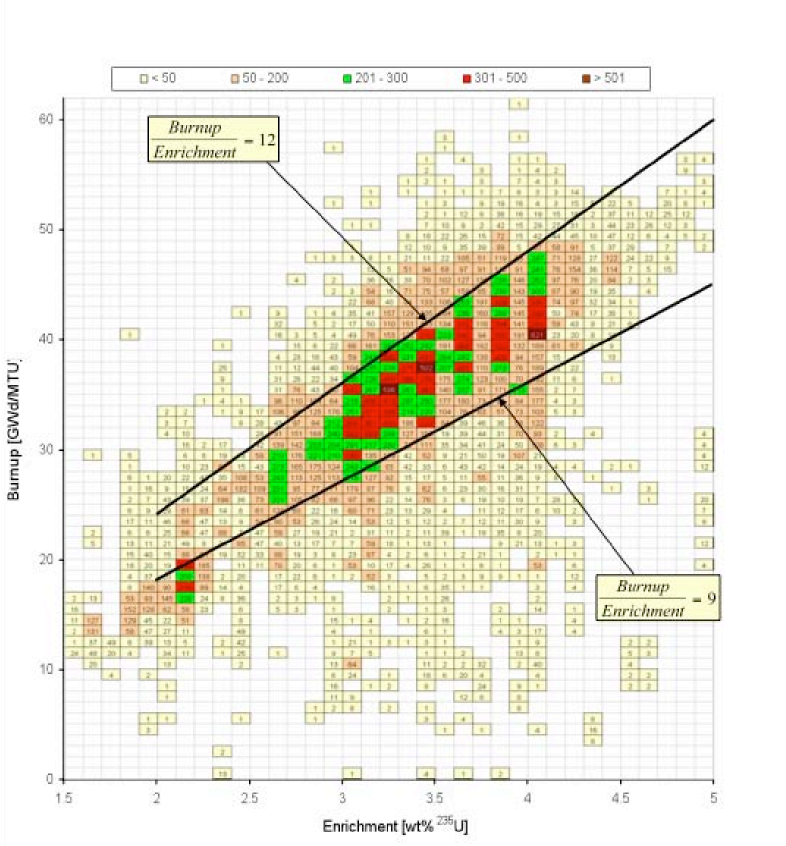
NUREG/CR-6800

Table 13 Summary table of Δk values due to variations in calculational assumptions for a typical discharge burnup and enrichment combination (40 GWd/MTU; 4.0 wt % ^{235}U) in the GBC-32 cask

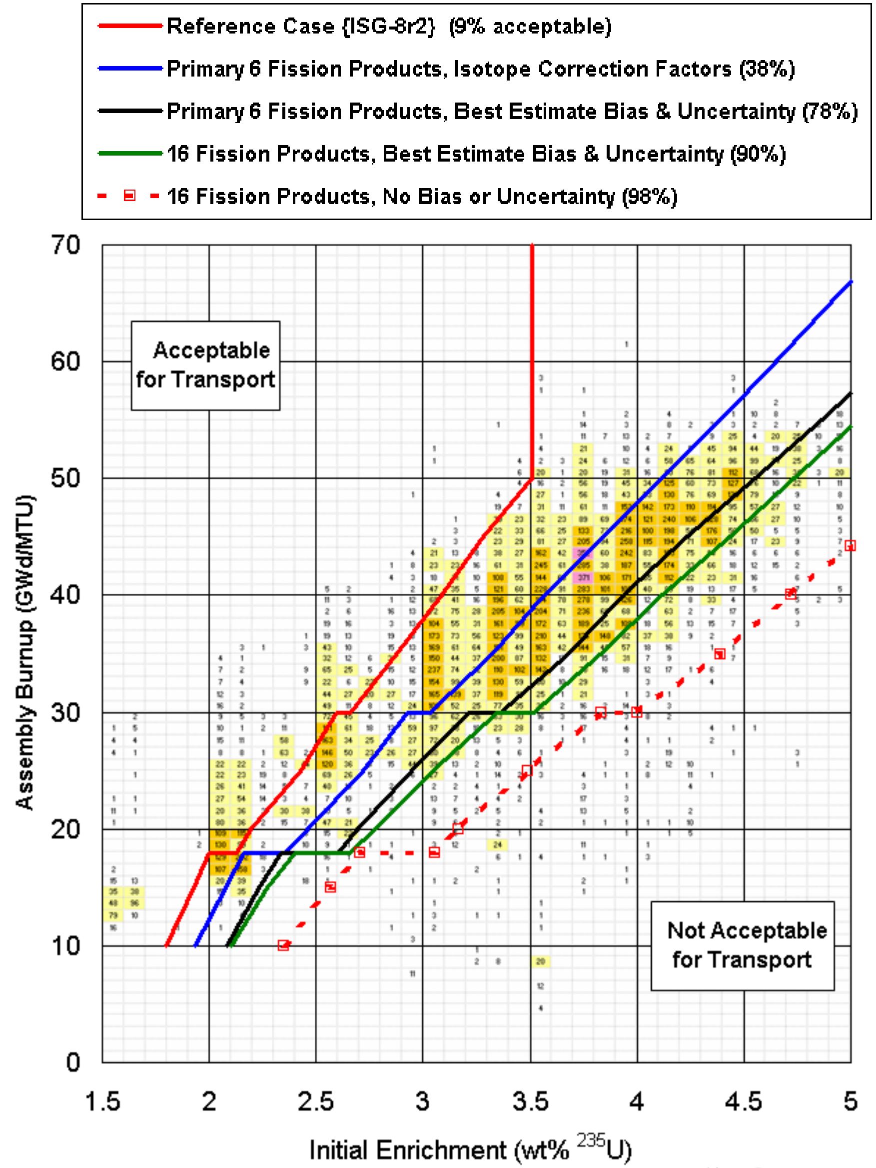
Modeling parameter/ characteristic	Assumptions used for comparison†		Δk values*	
	Base assumption	Bounding assumption	Actinide-only	Actinide + fission products
Fuel temperature during depletion	850 K	1100 K	0.0045	0.0031
Moderator temperature during depletion	595 K	610 K	0.0083	0.0088
Soluble boron concentration during depletion	600 ppm	1000 ppm	0.0042	0.0038
Specific power during depletion	40 MW/MTU	60 MW/MTU	< the statistical uncertainty	0.0008
Total of all depletion parameters listed above	All values listed above	All values listed above	0.0185‡	0.0154
BPRs during depletion	None	Inserted for first 20 GWd/MTU of burnup	0.0080	0.0062
CRs during depletion	None	Fully-inserted for first 5 GWd/MTU of burnup	0.0062	0.0070
Axial-burnup variation	Uniform	Reference profile from Table 1	0.0111	0.0337
Horizontal-burnup variation	Uniform	20% gradient	0.0023	0.0021
ICFs	None	Set 1 ICFs from Table 8	0.0325	0.0482

Reactivity Margins, (cont'd)

- Quantified large impact of ICFs
- Confirmed need for FP credit

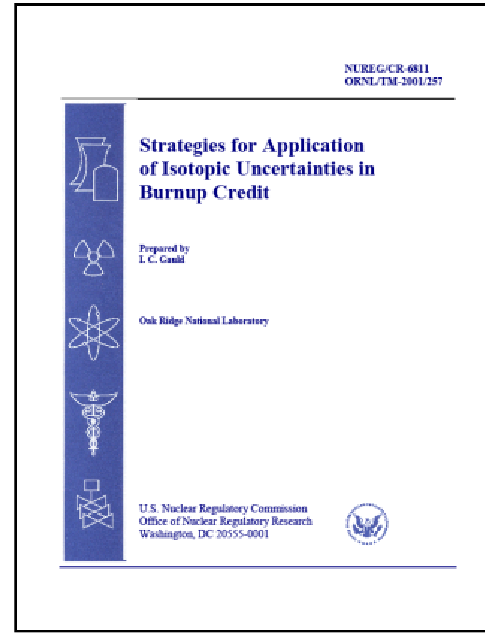


US PWR discharge data through 1998



Isotopic Validation, 2003

- Examined strategies for addressing uncertainties in predicted isotopic comps.
  - Reviewed/applied methods and data
    - Bounding methods
    - Best estimate methods
      - Monte Carlo sampling
      - Sensitivity coefficient analysis
      - Direct isotopic differencing


NUREG/CR-6811
ORNL/TM-2001/257

Strategies for Application of Isotopic Uncertainties in Burnup Credit

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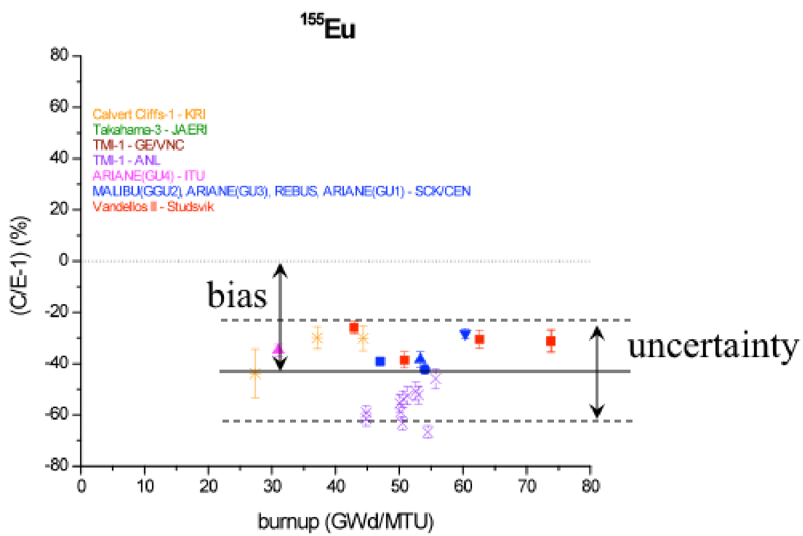
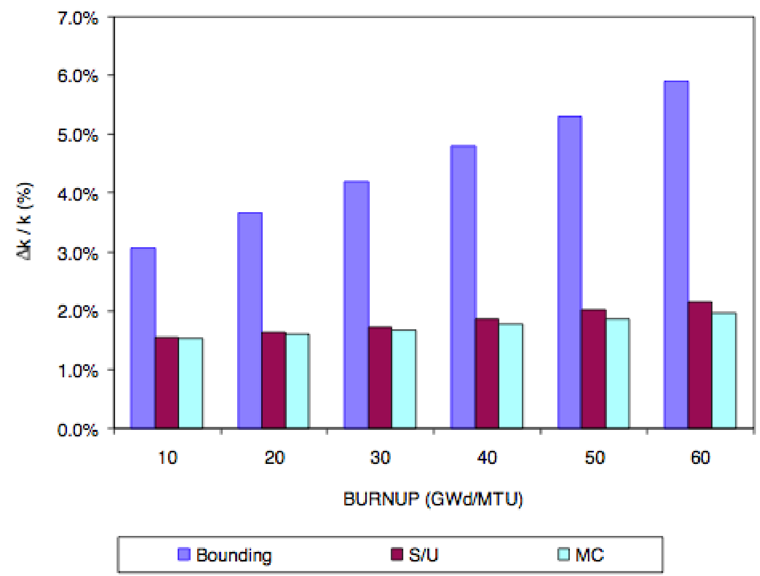
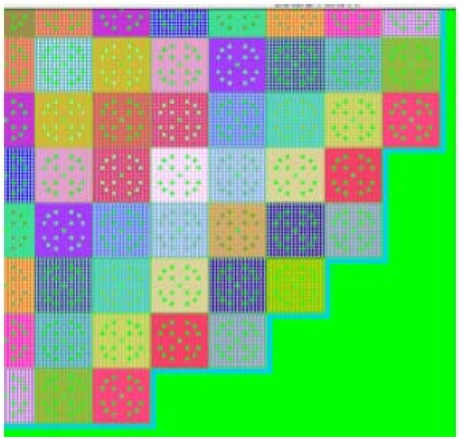
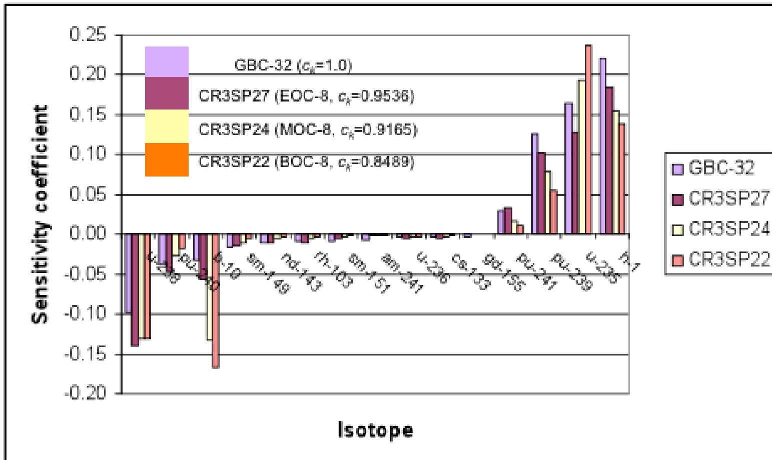


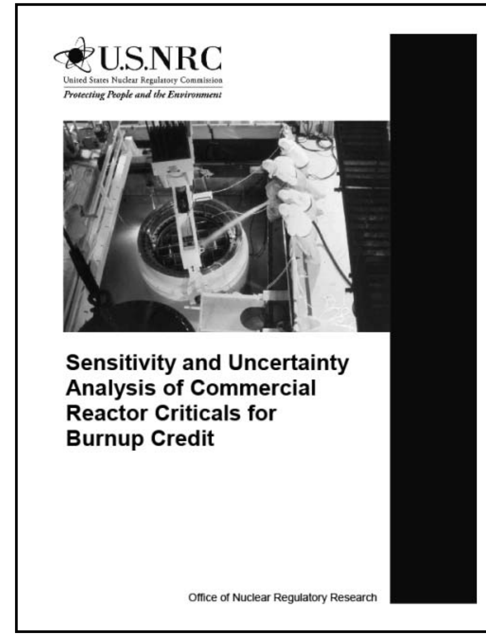


Applicability of CRCs, 2008

- Examined neutronic similarities between a SNF cask and 40 CRC state-points







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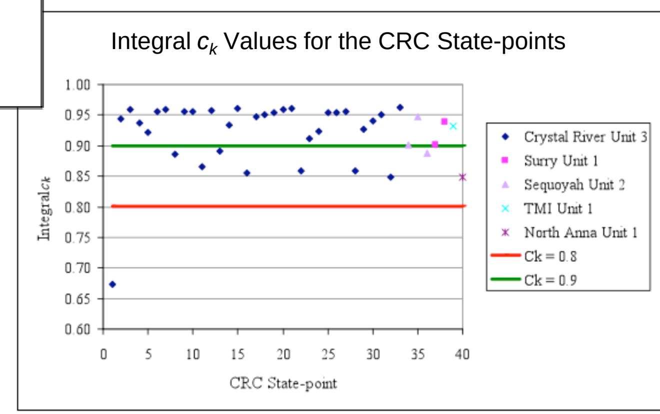
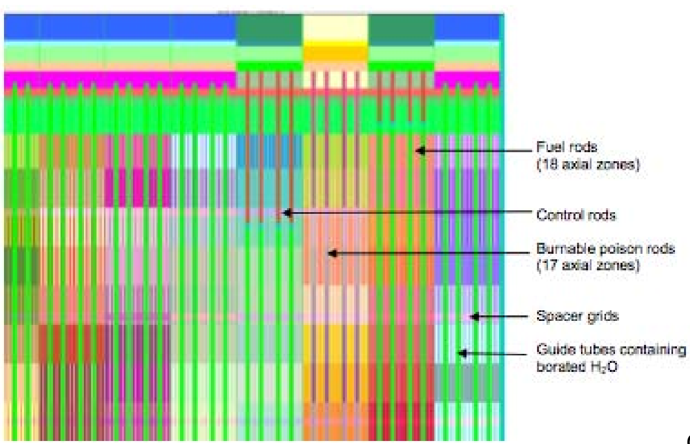
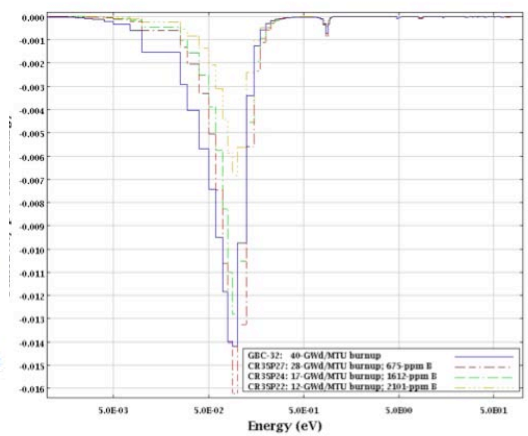




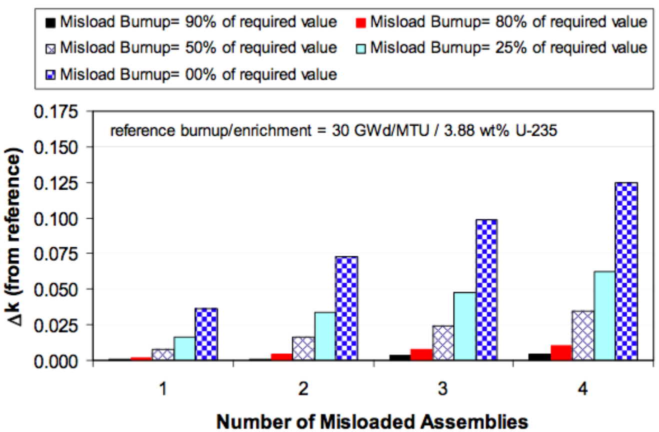


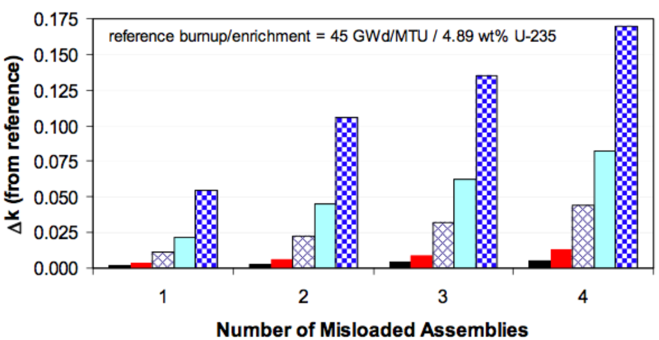
Comparison of ^{149}Sm Sensitivity Profiles for GBC-32, CR3 State-points 27 (EOC-8), 24 (MOC-8), & 22 (BOC-8)

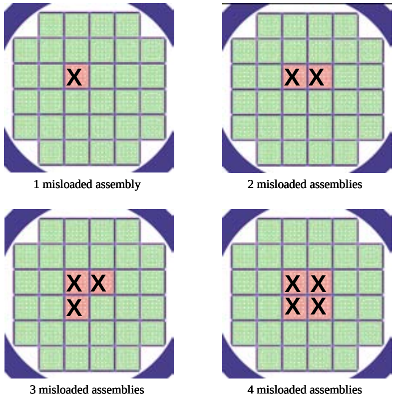
CRCs found to be good in terms of applicability; how to address uncertainties?

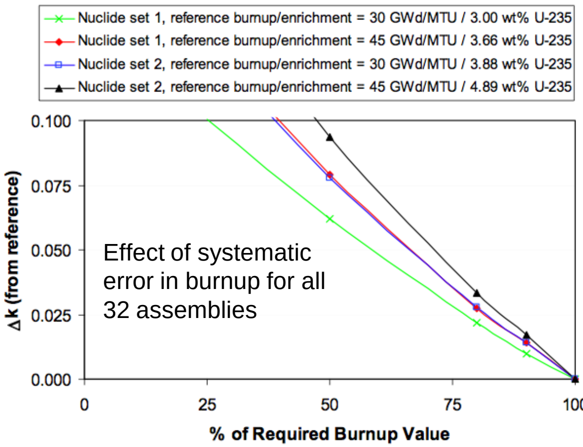
Assembly Misloading, 2008

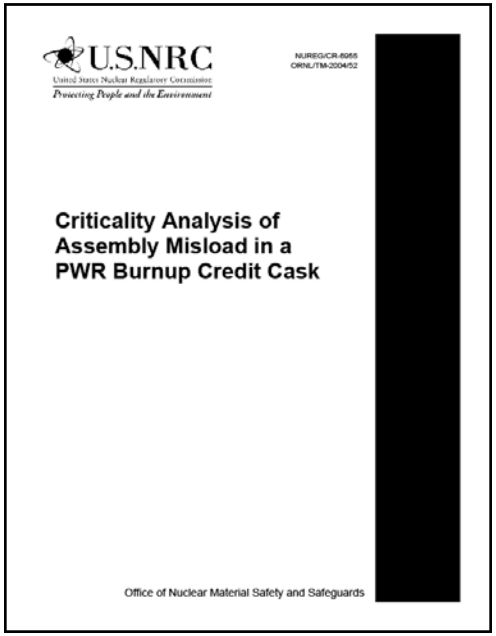
- Examined effect of fuel misloading on k_{eff}
- A variety of fuel-misloading configurations were investigated to understand impact









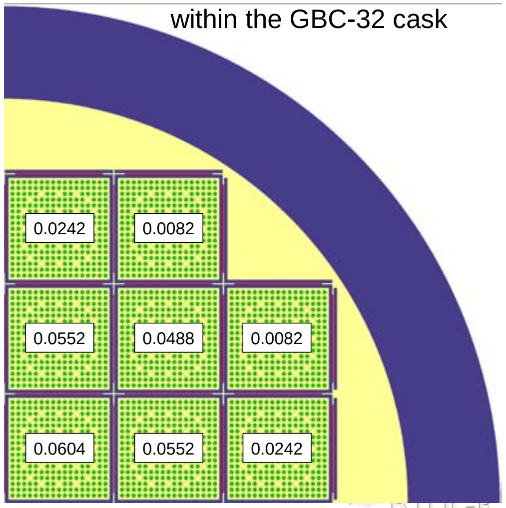

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment
NUREG/CR-6955
ORNL/TM-2004/52

Criticality Analysis of Assembly Misload in a PWR Burnup Credit Cask

Office of Nuclear Material Safety and Safeguards

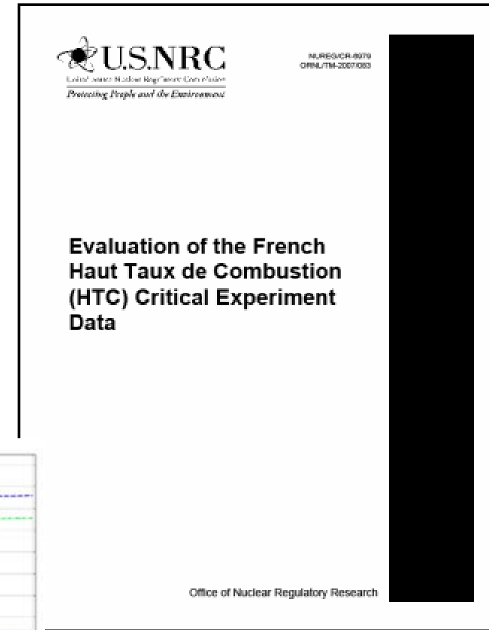
NUREG/CR-6955

Δk effect of misloading a single fresh assembly with 5 wt% ^{235}U enrichment in different locations within the GBC-32 cask

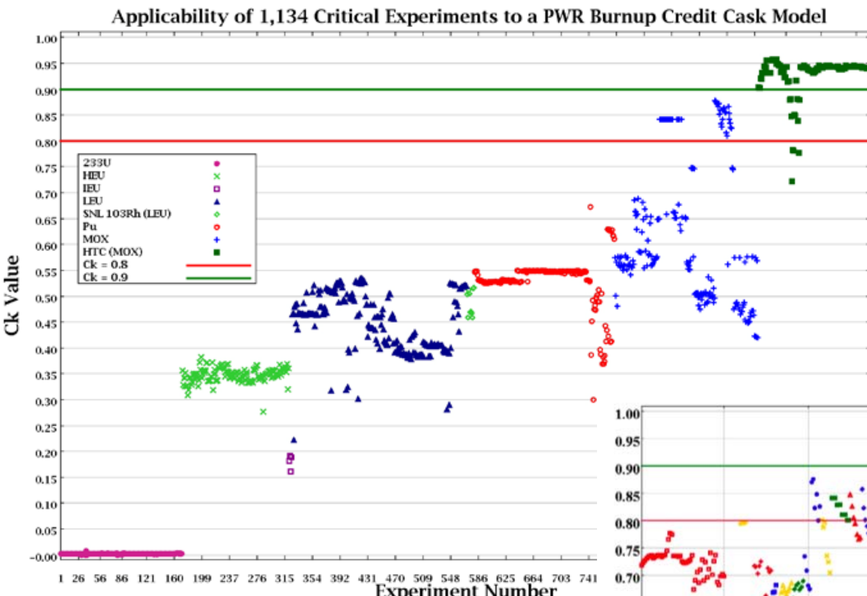


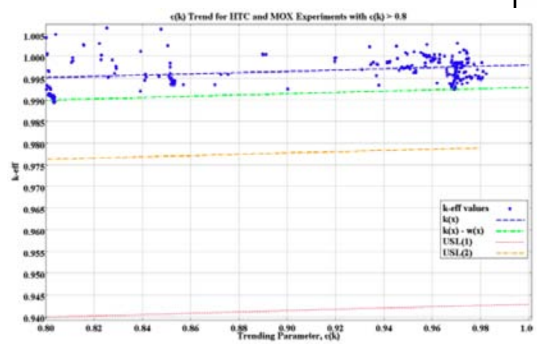
Criticality Validation–HTC data

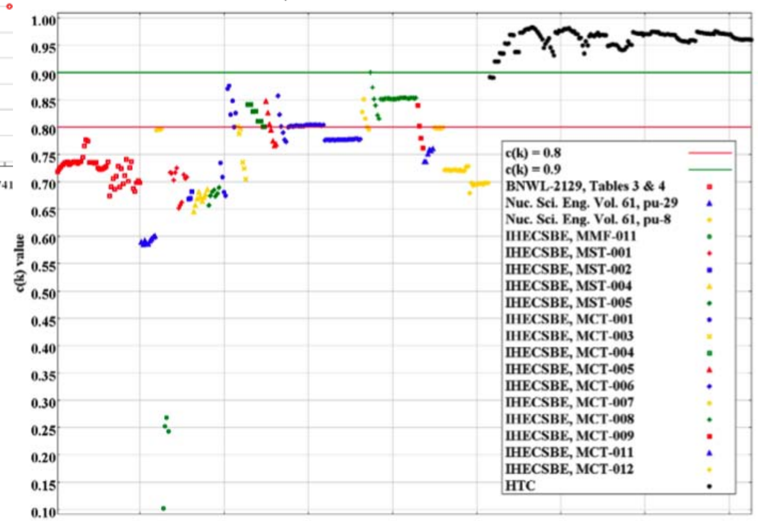
- Examined applicability/usefulness of French critical experiments (Valduc) for actinide validation
  - 156 configurations with designed to mimic 4.5 wt% ^{235}U initial enrichment fuel burned to 37.5 GWd/MTU in storage & transport conditions

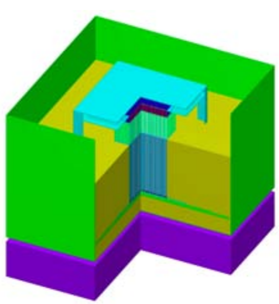


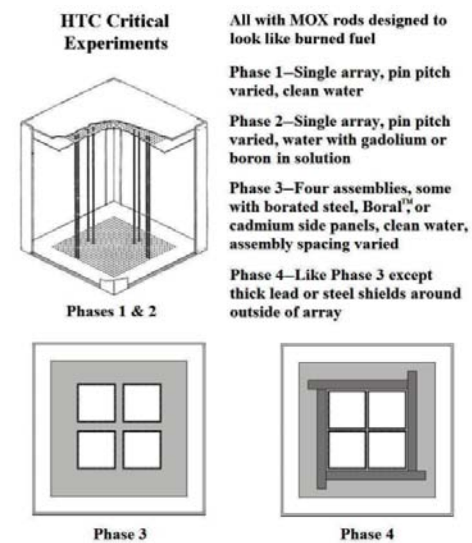
NUREG/CR-6979







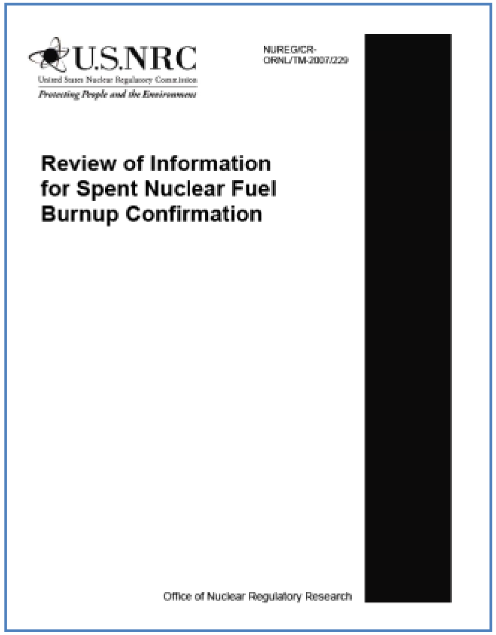




International Workshop on Advances in Applications of Burnup Credit for Spent Fuel Storage, Transport, Reprocessing and Disposition, Cordoba, Spain, Oct 27-30, 2009

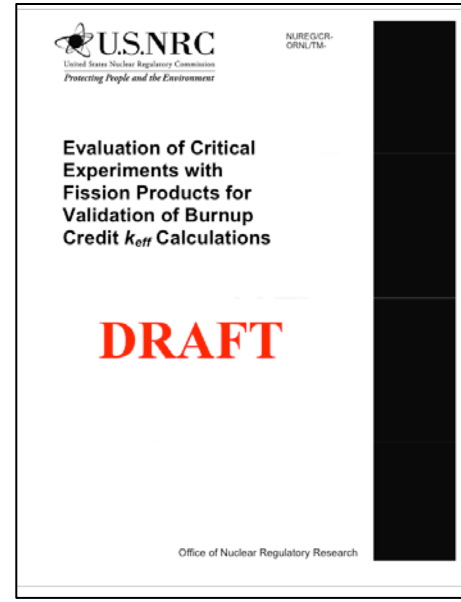
Burnup Confirmation

- Provides information and issues relevant to pre-shipment burnup measurements when using burnup credit in PWR SNF storage & transport casks
- The report provides a review of:
  - the role of burnup measurements in the regulatory guidance (ISG-8) for demonstrating compliance with burnup loading criteria
  - burnup measurement capabilities and experience
  - accuracy of utility burnup records
  - fuel movement and misloading experience
  - the consequences of misloading assemblies in casks designed for burnup credit
- The report also provides observations based on the review
- Report being finalized

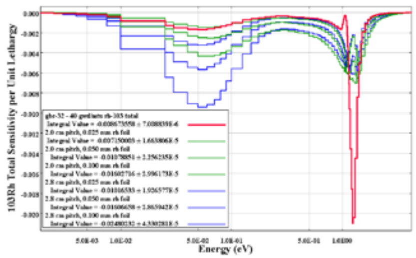

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment
NUREG/CR-
ORNL/TM-2007/229
Review of Information for Spent Nuclear Fuel Burnup Confirmation
Office of Nuclear Regulatory Research

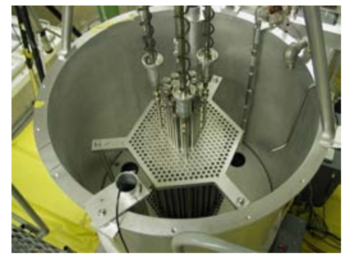
NUREG/CR-????

Current Focus Area – FP Validation

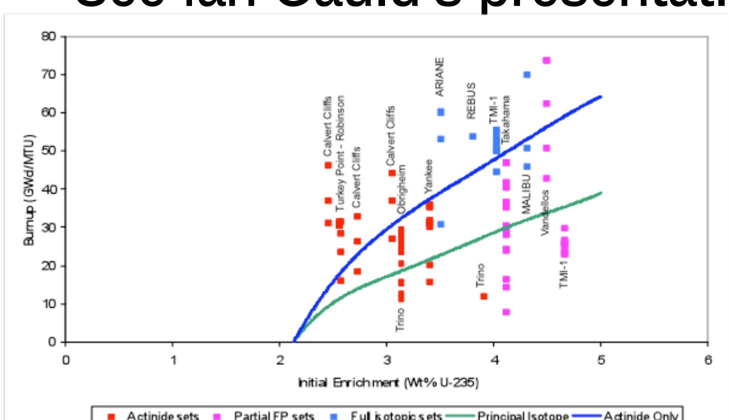


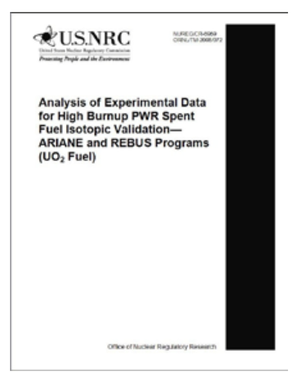
- Methods and data for criticality validation with FPs
  - See Don Mueller's presentation Wednesday PM

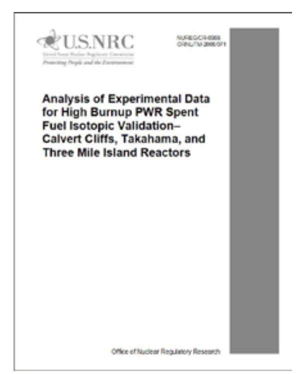


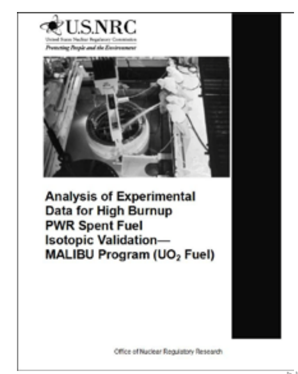


- Methods and data for isotopic validation with FPs
  - See Ian Gauld's presentation on Wednesday PM









Other Technical Resources

- OECD/NEA Expert Group publications
- Meeting proceedings and journal articles
- Technical reports from US DOE and other organizations
- Regulatory guidance/standards from safety authorities
- ANSI/ANS-8.27-2008: Burnup Credit for LWR Fuel

- Burnup credit bibliographies:
  – http://www.ornl.gov/sci/radiation_transport_criticality/BUCPublications..htm
  – See: http://www.nea.fr/html/science/wpncs/buc/index.html

Concluding Remarks

- US NRC initiated and maintained a research program to address burnup credit technical issues with the goal of allowing and expanding the use of burnup credit in PWR SNF storage and transport applications
- A great deal of work has been performed by ORNL and others in the US and abroad, particularly for PWR SNF
- Hopefully this work is and will be useful to others for
  - Learning and understanding issues
  - Reducing redundant work, thereby enabling focused efforts on remaining important technical issues

Current and Expected Future Activities

- Methods and approaches for FP validation
- BWR burnup credit